Robot Programming #14

Mechatronics and Robot

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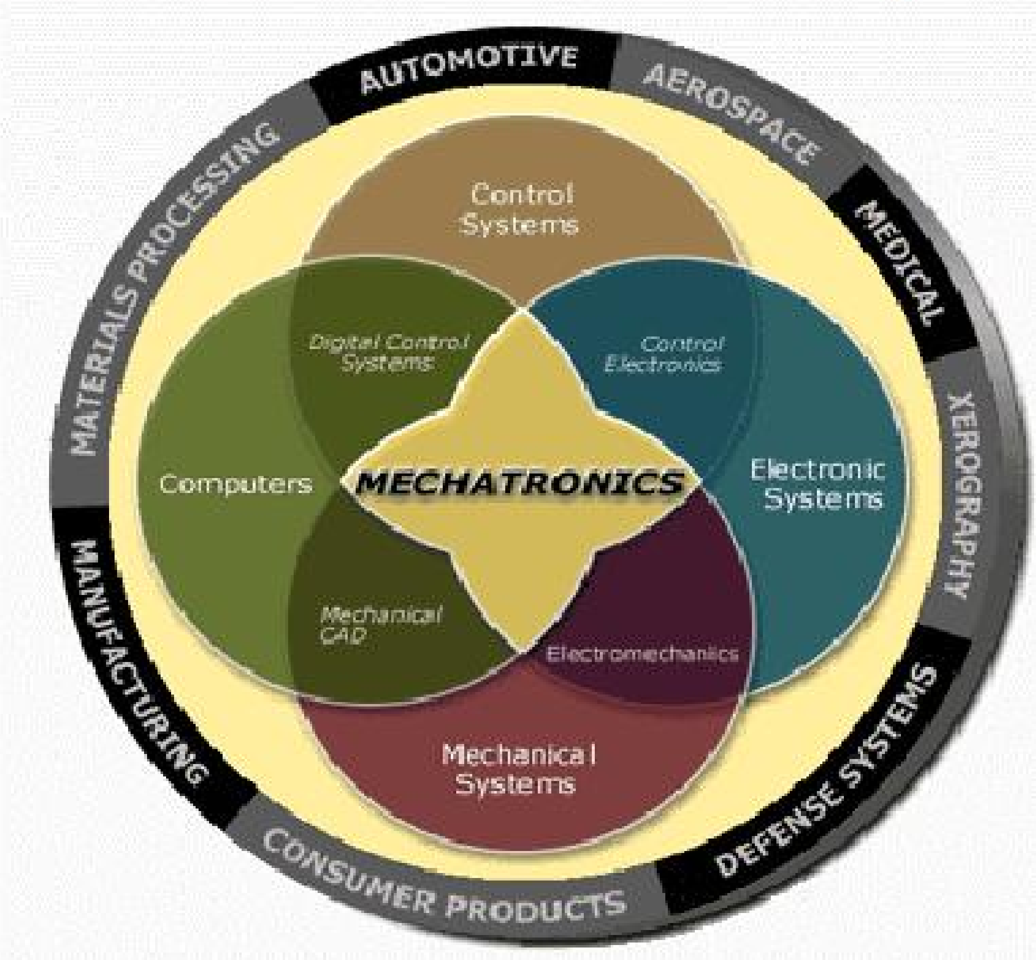
Introduction

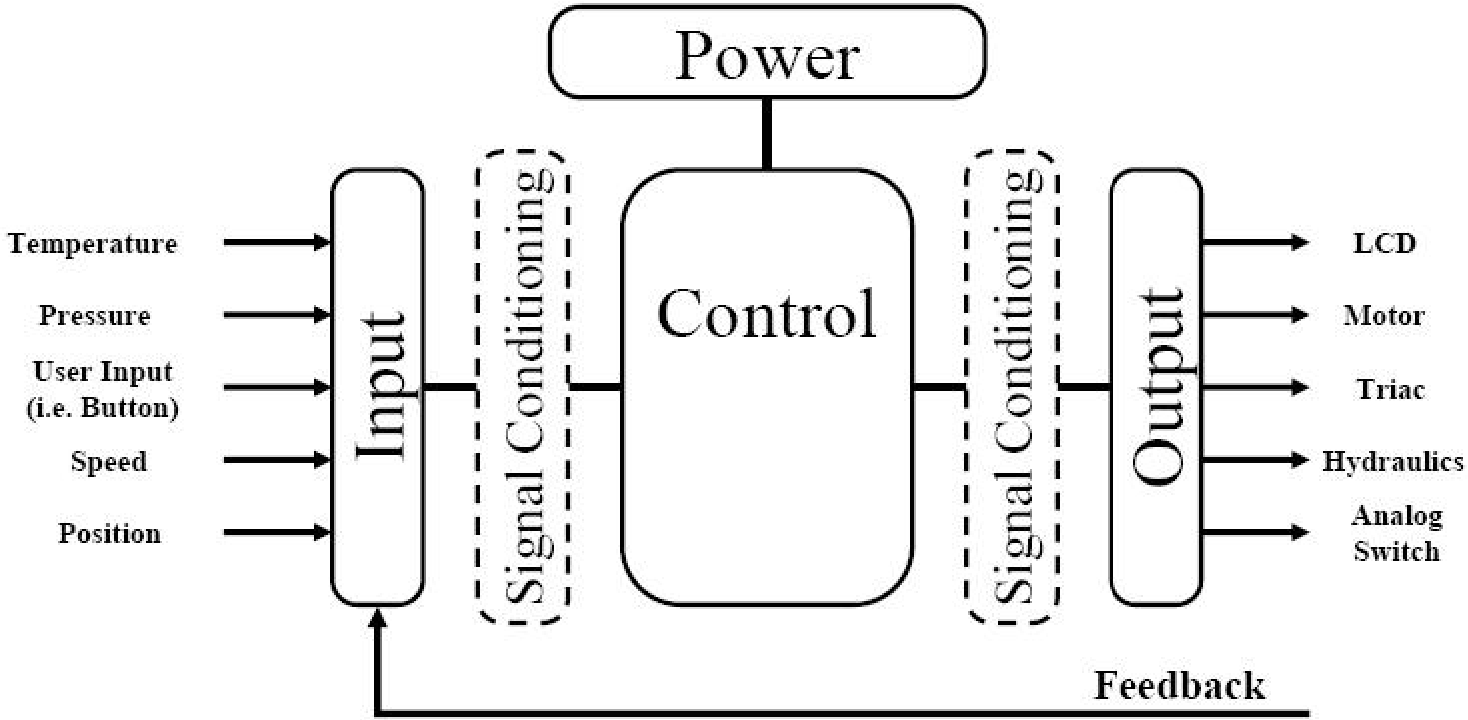
What is Mechatronics?

Mechatronics is the ***synergistic*** combination of mechanical engineering, electronics, controls engineering, and computers, all ***integrated*** through the design process.



Mechatronics

- System Level



Mechatronics in general

- Mechatronics design center content

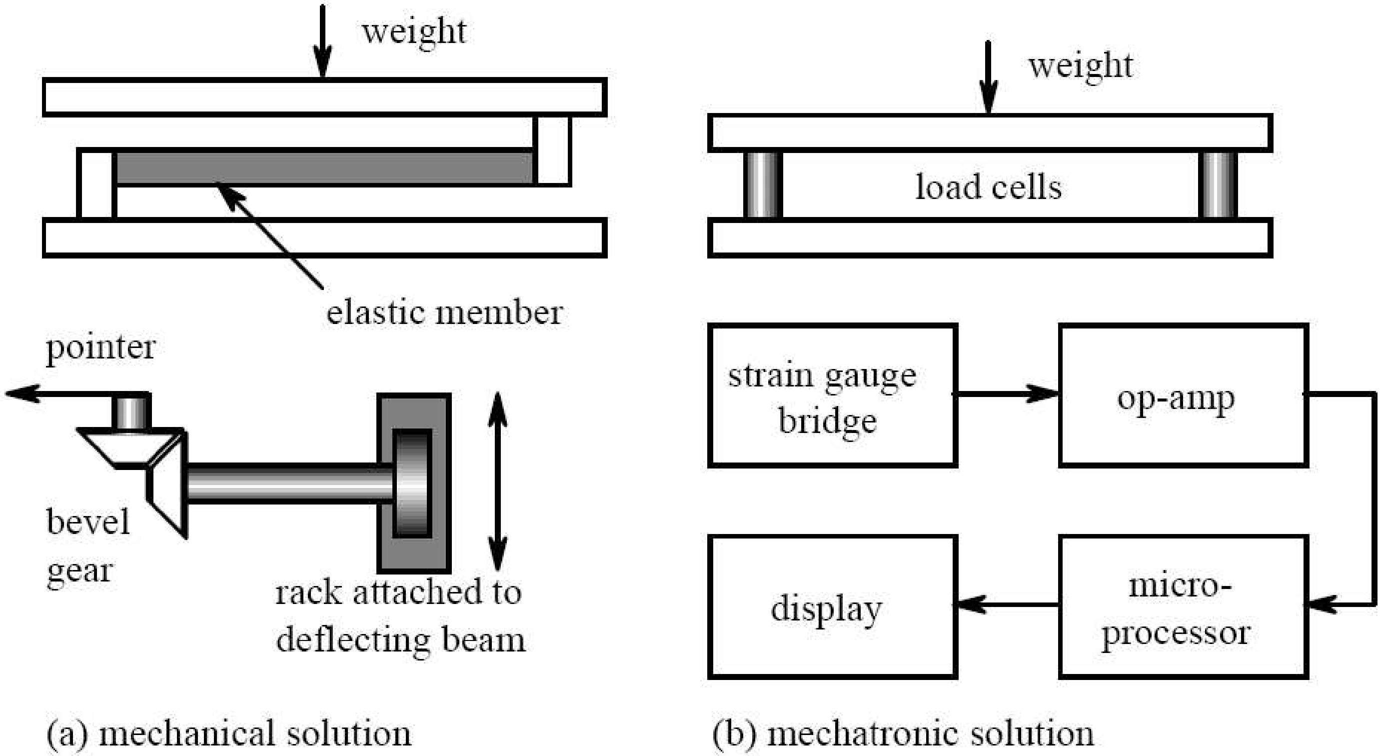
Input	Output	Power	Signal Conditioning	Control
User Inputs (Switches, Potentiometers)	Displays (LCDs, LEDs)	AC (wall power)	Analog-to-Digital Conversion	PID
Temperature Sensor	Motors	DC Battery, Low Power, DC-to-DC Regulators	Digital-to-Analog Conversion	Digital Filtering
Pressure Sensor	Triac (AC switcher)		Analog Filtering	Math Routines
Position/Speed	Communication Interface		Op Amps and Programmable Gain Amplifiers	
Communication Interface			Comparators	
			Volt. to Freq. and Freq. to Volt.	

Examples: Bathroom Scales

- Bathroom scale

Example: Bathroom Scales

- Mechanical vs. mechatronic scale

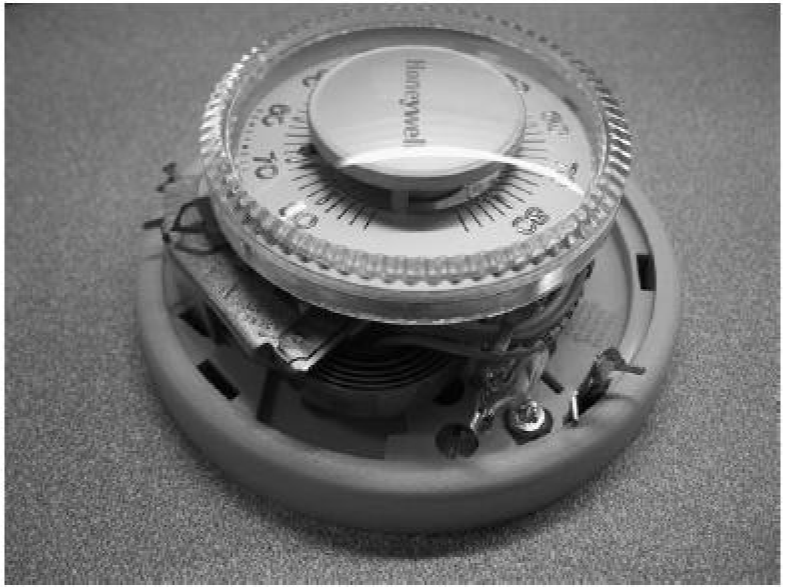


Examples: Bathroom Scales

- Mechanical solution: elastic member
  - Deflection can be transformed into the movement of a pointer
  - Mechanical mechanisms
- Mechatronic solution
  - Platform-loadcell-electrical strain gauges
  - Gauges strained – changed resistance
  - Small signal input into differential OP amp
  - Amplified signal input into microprocessor via A/D converter
  - Display driven by microprocessor: weight calculated and displayed via LEDs or LCD

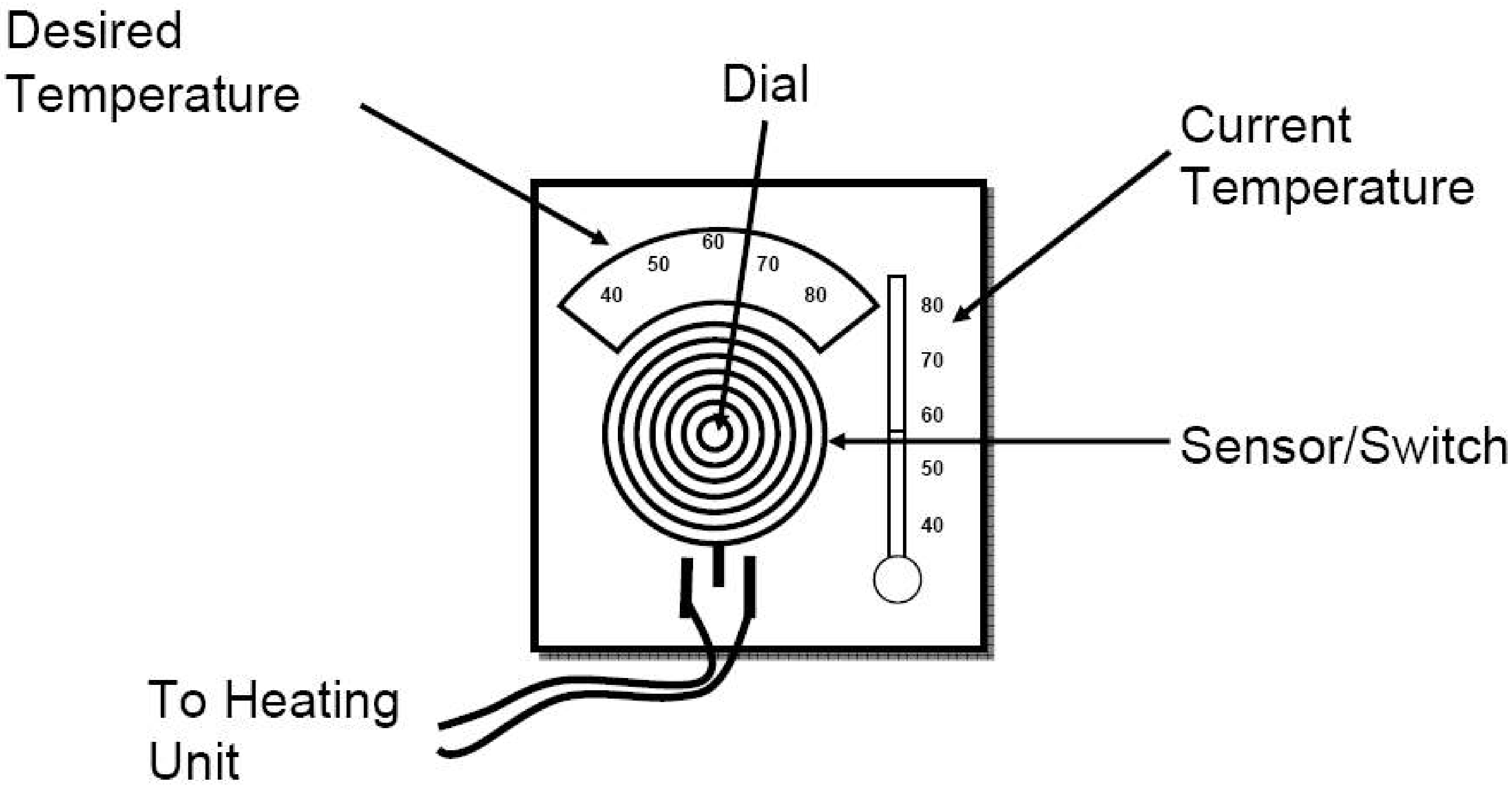
Examples: Household Thermostat

- Mechanical vs. mechatronic thermostat



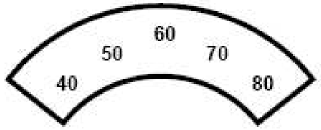
Examples: Household Thermostat

- Traditional Thermostat

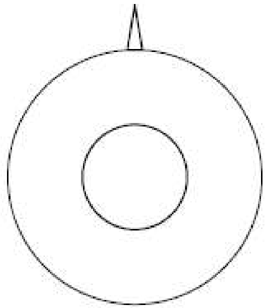


Examples: Household Thermostat

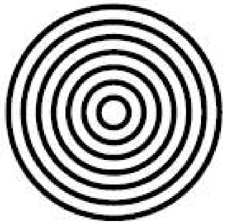
- Breakdown of Thermostat



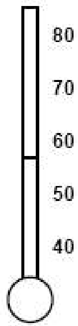
User Feedback



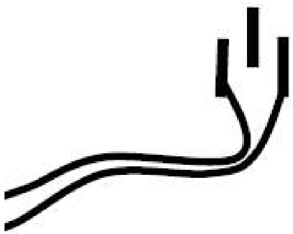
User Input



Temperature
Sensor



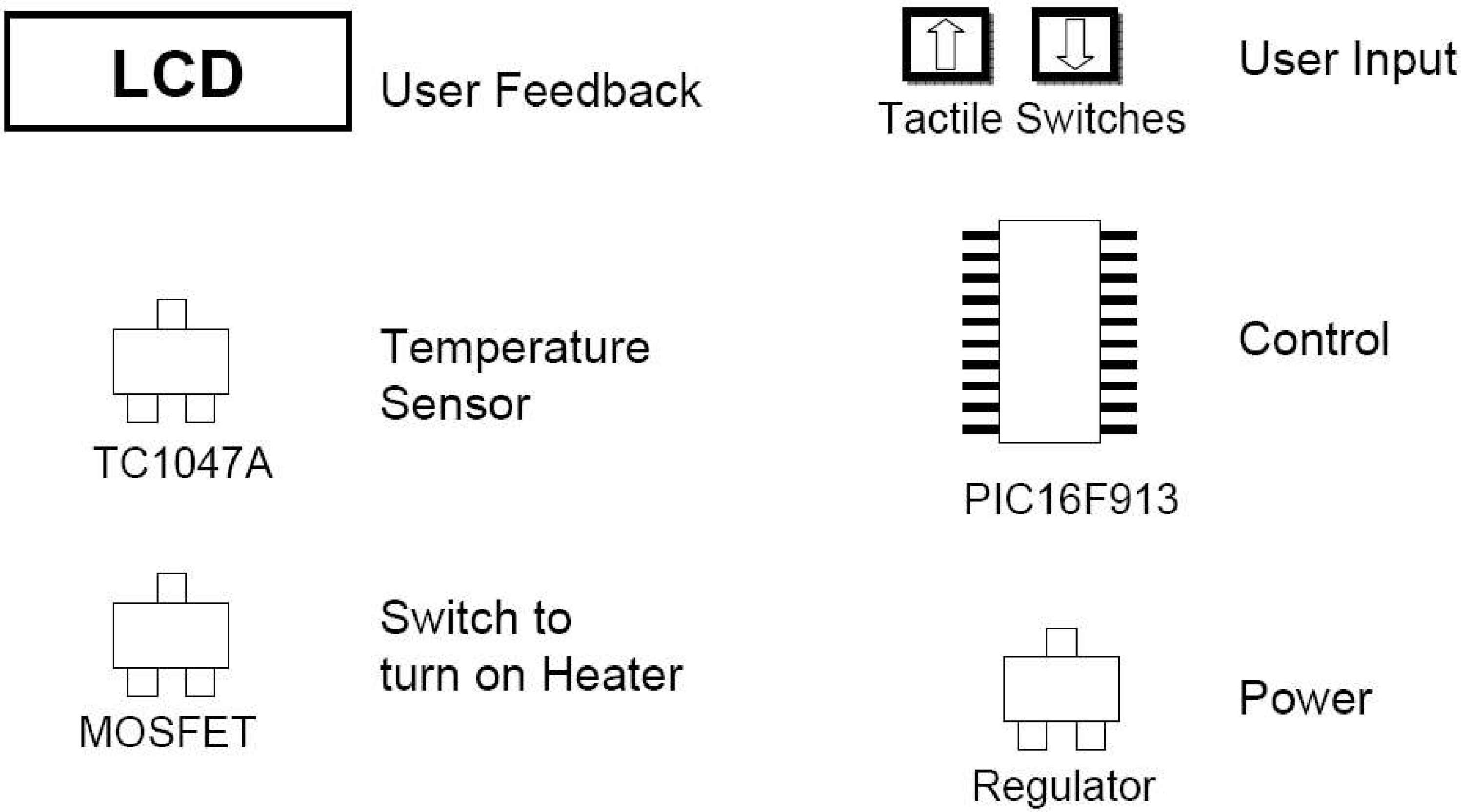
User Feedback



Switch to
turn on Heater

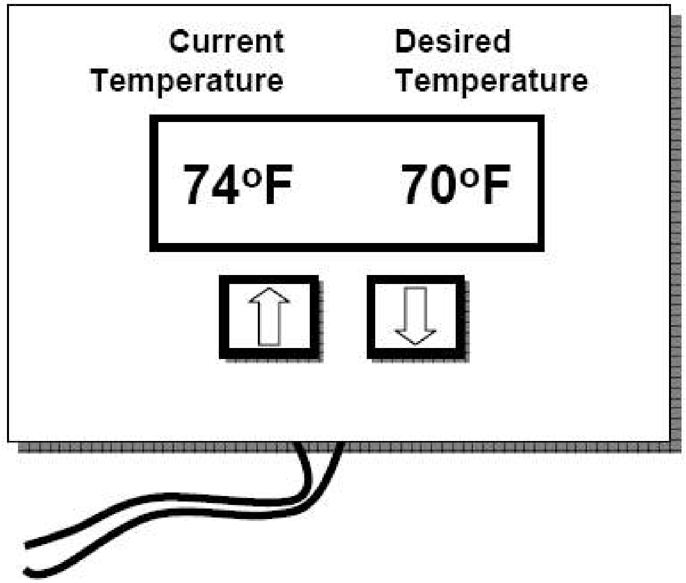
Examples: Household Thermostat

- Conversion to mechatronics design



Examples: Household Thermostat

- Final Design



  - Higher resolution and accuracy
  - Reduce household heating cost
  - Self calibrating
  - Flexible design
  - Environmentally friendly

Advantage of Using Mechatronics

- Flexibility
- Durability
- Simple mechanical construction
- Functionality transferred to electronics
- Possibility of adding functionality at low cost
- Higher accuracy
- Cost – same as conventional

How mechatronics comes to reality

- **transistor** invented in 1948
- integrated circuit technology - a leap forward
- micro-miniaturization - an on-going process
- in the 70’s **- microprocessor (μP)** appeared on the market
- revolutionized the **intelligence incorporated in consumer products & industrial systems**
- In the 80’s - a true explosion in microprocessor based products happened.
- Now it turns into Robots with IoT.

Mechatronics Products

- **consumer sector**
  - Microwaves, washing machine, dishwasher, CD players
  - Camcorder, auto-focus, auto exposure camera etc.
- **commercial sector**
  - automated teller machine (ATM) etc.
- **industrial sector**
  - CNC machine tools
  - Mobile robots
- **automotive industry**
  - active suspension systems etc.
- **Architecture**
  - Automatic blind control
  - security

Traditional vs. Mechatronics

- Traditional Approach
  - Bulky system
  - Complex mechanism
  - Non-adjustable movements
  - Constant speed drives
  - Mechanical synchronization
  - Manual controls
- Mechatronics Approach
  - Compact
  - Simplified mechanism
  - Programmable motion
  - Variable speed drive
  - Electronic synchronization
  - Automatic & programmable controls

Robots and Mechatronics

- Robotics is a part of mechatronics.
- Mechatronic solutions are used in building a robot.

How to make a robot

- Choosing a Robotic Platform.
- Making Sense of Actuators.
- Understanding Microcontrollers
- Choosing a Motor Controller
- Controlling your Robot
- Using Sensors
- Getting the Right Tools
- Assembling a Robot
- Programming a Robot

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Choosing a Robotic Platform

- A custom robot design often starts with a “vision” of what the robot will look like and what it will do.
  - Land wheeled, tracked, and legged robots
  - Aerial planes, helicopters, and blimp
  - Aquatic boats, submarines, and swimming robots
  - Misc. and mixed robots
  - Stationary robot arms, and manipulators

Choosing a Robotic Platform

Yamabico

MagellanPro

Sojourner

ATRV-2

Hilare 2-Bis

Koy

Choosing a Robotic Platform

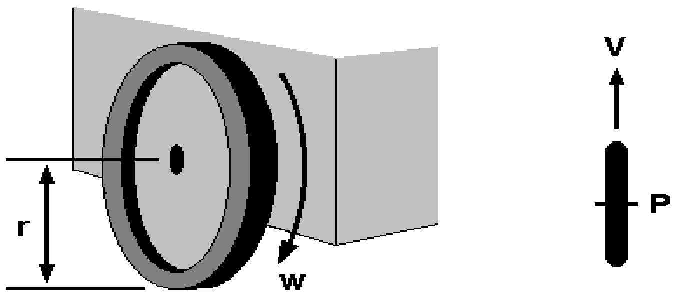
- **Locomotion —** the process of causing an robot to move.
  - In order to produce motion, forces must be applied to the robot
  - Motor output, payload

- **Kinematics** – study of the mathematics of motion without considering the forces that affect the motion.
  - Deals with the geometric relationships that govern the system
  - Deals with the relationship between control parameters and the behavior of a system.

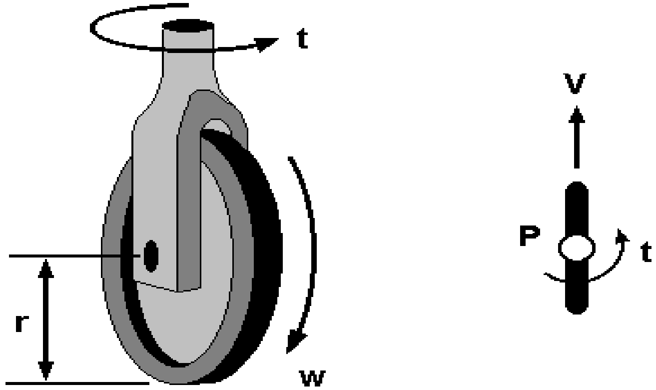
- **Dynamics** – study of motion in which these forces are modeled
  - Deals with the relationship between force and motions.

Wheel Type

Fixed wheel

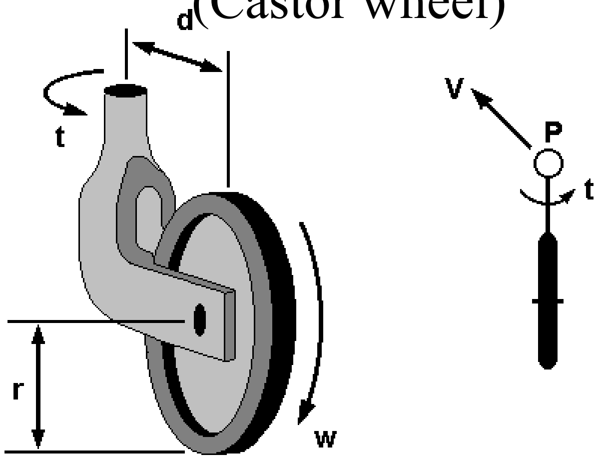


Centered orientable wheel

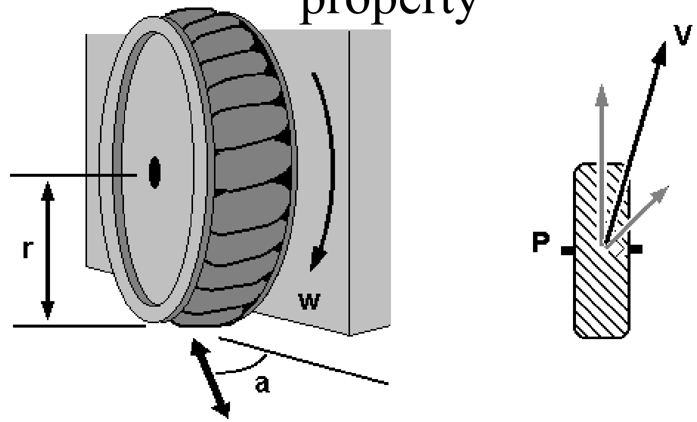


Off-centered orientable wheel

(Castor wheel)

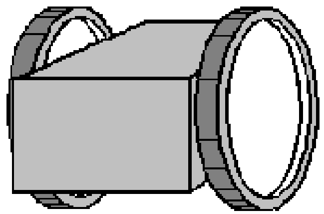


Swedish wheel:omnidirectional property



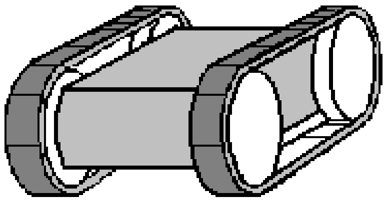
Wheeled Mobile Robot

- Types used for wheeled mobile robot



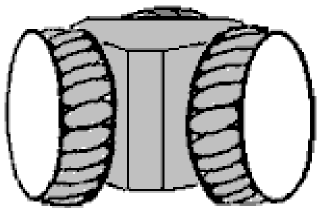
Bi-wheel type robot

- Smooth motion
- Risk of slipping
- Some times use roller-ball to make balance



Caterpillar type robot

- Exact straight motion
- Robust to slipping
- Inexact modeling of turning



Omni-directional robot

- Free motion
- Complex structure
- Weakness of the frame

Land – Wheeled Robots



- Advantages
  - Usually low-cost compared to other methods
  - Simple design and construction
  - Abundance of choice
  - Six wheels or more rival a track system
  - Excellent choice for beginners
- Disadvantages
  - May lose traction (slip)
  - Small contact area (only a small rectangle or line underneath each wheel is in contact with the ground)

Land – Tracked Robots



- Advantages
  - Constant contact with the ground prevents slipping
  - Evenly distributed weight helps your robot tackle a variety of surfaces
  - Can be used to significantly increase a robot's ground clearance without incorporating a larger drive wheel
- Disadvantages
  - When turning, there is a sideways force that acts on the ground; this can cause damage to the surface
  - Not many different tracks are available.
  - Increased mechanical complexity.

Land - Legs

Hexapods(six legs) Biped(two legs) quadrupeds(four legs)

- Advantages
  - Closer to organic or natural motion
  - Can potentially overcome large obstacles and navigate very rough terrain

- Disadvantages
  - Increased mechanical, electronic and coding complexity (not the easiest way to get into robotics).
  - Lower battery size despite increased power demands
  - Higher cost to build

Air



- Advantages
  - Remote controlled aircraft have been in existence for decades (so there is a large community, at least for the mechanics)
  - Excellent for surveillance
- Disadvantages
  - The entire investment can be lost in one crash.
  - Limited robotic community to provide help for autonomous control

Water

- Advantages
  - Most of our planet is water, so there is a lot to explore and discover
  - Design is almost guaranteed to be unique
  - Can be used and/or tested in a pool
- Disadvantages
  - Robot can be lost many ways (sinking, leaking, entangled…)
  - Most electronic parts do not like water (also consider water falling on electronics when accessing the robot after a dive)
  - Surpassing depths of 10m or more can require significant research and investment
  - Very limited robotic community to provide help
  - Limited wireless communication options

Arms & Grippers

- Advantages
  - Very simple to very complex design possibilities
  - Easy to make a 3 or 4 degree of freedom robot arm (two joints and turning base)
- Disadvantages
  - Stationary unless mounted on a mobile platform
  - Cost to build is proportional to lifting capability

How to make a robot

- **Choosing a Robotic Platform.**
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Making Sense of Actuators

- What is an actuator?
- An “actuator” can be defined as a device that converts energy (in robotics, that energy tends to be electrical) into physical motion. The vast majority of actuators produce either rotational or linear motion. For instance, a “DC motor” is therefore a type of actuator.

Rotational Actuator – AC Motors

- AC (alternating current) is rarely used in mobile robots since most of them are powered with direct current (DC) coming from batteries. Also, since electronic components use DC, it is more convenient to have the same type of power supply for the actuators as well. AC motors are mainly used in industrial environments where very high torque is required, or where the motors are connected to the mains / wall outlet.

Rotational Actuator – DC Motors

- DC motors come in a variety of shapes and sized although most are cylindrical. They feature an output shaft which rotates at high speeds usually in the 5 000 to 10 000 rpm range. Although DC motors rotate very quickly in general, most are not *strong* (low torque). In order to reduce the speed and increase the torque, a gear can be added.

Rotational Actuator – Geared DC Motors

- A DC gear motor is a DC motor combined with a gearbox that works to decrease the motor's speed and increase the torque.
- The most common types of gearing are "spur" (the most common), "planetary" (more complex but allows for higher gear-downs in a more confined space, as well as higher efficiency) and "worm" (which allows for very high gear ratio with just a single stage, and also prevents the output shaft from moving if the motor s not powered).

Rotational Actuator – R/C Servo Motors

- R/C (or hobby) servo motors are types of actuators that rotate to a specific angular position, and were classically used in more expensive remote controlled vehicles for steering or controlling flight surfaces.

Rotational Actuator – Industrial Servo Motors

- An industrial servo motor is controlled differently than a hobby servo motor and is more commonly found on very large machines. An industrial servo motor is usually made up of a large AC (sometimes three-phase) motor, a gear down and an encoder which provides feedback about angular position and speed.

Rotational Actuator – Stepper Motors

- A stepper motor does exactly as its name implies; it rotates in specified "steps" (actually, specific degrees). The number of degrees the shaft rotates with each step (step size) varies based on several factors. Most stepper motors do not include gearing, so just like a DC motor, the torque is often low.

Linear Actuator – DC Linear Actuator

- A DC linear actuator is often made up of a DC motor connected to a lead screw. As the motor turns, so does the lead screw.

Linear Actuator – Solenoids

- Solenoids are composed of a coil wound around a mobile core. When the coil is energized, the core is pushed away from the magnetic field and produces a motion in a single direction.

Linear Actuator – Muscle Wire

- Muscle wire is a special type of wire that will contract when an electric current traverses it. Once the current is gone (and the wire cools down) it returns to its original length.

Linear Actuator – Pneumatic and Hydroraulic

- Pneumatic and hydraulic actuators use air or a liquid (e.g. water or oil) respectively in order to produce a linear motion. These types of actuators can have very long strokes, high force and high speed.

Choosing an Actuator

- Is the actuator being used to move a wheeled robot?
- Is the motor being used to lift or turn a heavy weight?
- Is the range of motion limited to 180 degrees?
- Does the angle need to be very precise?
- Is the motion in a straight line?

- Motor Selection Tool

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What is a microcontroller?

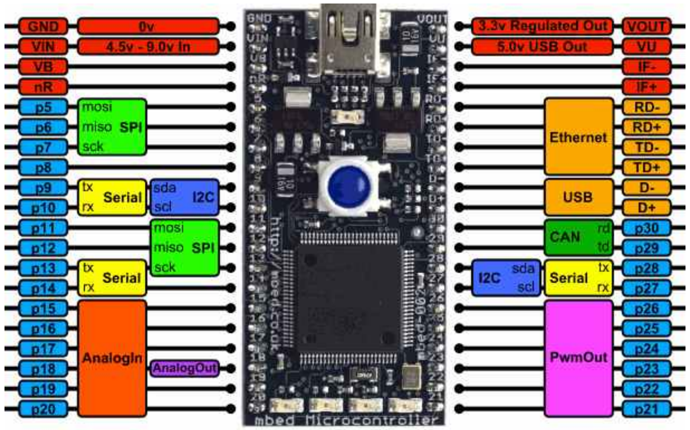
- A microcontroller is a computing device capable of executing a program (i.e. a sequence of instructions) and is often referred to as the “brain” or “control center” in a robot since it is usually responsible for all computations, decision making, and communications.
- In order to interact with the outside world, a microcontroller possesses a series of pins (electrical signal connections) that can be turned HIGH (1/ON), or LOW (0/OFF) through programming instructions.

What can a microcontroller do?

- Many complex actions can be achieved by setting the pins HIGH and LOW in a clever way.
- Creating very complex algorithms (such as advanced vision processing and intelligent behaviors) or very large programs may be simply impossible for a microcontroller due to its inherent resource and speed limitations.
- It is important to note that a microcontroller can output only a very small amount of electrical power through its pins; this means that a generic microcontroller will likely not be able to power electrical motors, solenoids, large lights, or any other large load directly.

Analogue or Digital

- Digital: A digital signal is used in order to assess the binary state of a switch.
- Analogue: A variable resistor or potentiometer (as shown towards the right side of the board below) is used to provide an analogue electrical signal proportional to a rotation (e.g. the volume knob on a stereo). The ADC on a microcontroller interprets the voltage and converts it to a numeric value.



What about programming?

- Being afraid of programming microcontrollers is getting old fashioned.
- Microcontrollers can be programmed in various high-level languages including C, C++, C#, Processing (a variation of C++), Java, Python, .Net, and Basic.

```
void setup() {
   pinMode(13, OUTPUT);
}

void loop() {
   digitalWrite(13, HIGH);
   delay(1000);
   digitalWrite(13, LOW);
   delay(1000);
}
```

```
#include "mbed.h"
DigitalOut myled(LED1);

int main() {
   while(1) {
      myled = 1;
      wait(1.0);
      myled = 0;
      wait(1.0);
   }
}
```

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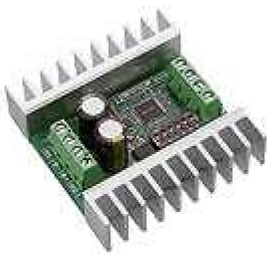
What is a motor controller?

- A motor controller is an electronic device (usually comes in the shape of a bare circuit board without enclosure) that acts as an intermediate device between a microcontroller, a power supply or batteries, and the motors.




Why do we need a motor controller?

- Although the microcontroller decides the speed and direction of the motors, it cannot drive them directly because of its very limited power(current and voltage) output.
- The motor controller can provide the current at the required voltage but cannot decide how fast the motor should turn.
- The microcontroller can instruct the motor controller on how to power the motors via a standard and simple communication method such as UART (a.k.a. serial) or PWM.

Motor Controller Types

- Brushed DC motor controllers: used with brushed DC, DC gear motors, and many linear actuators.
- Brushless DC motor controllers: used with brushless DC motors.
- Servo Motor Controllers: used for hobby servo motors
- Stepper Motor Controllers: used with unipolar or bipolar stepper motors depending on their kind.

Choosing a Motor Controller – DC Motor

- The first consideration is the motor's **nominal voltage**. DC motor controllers tend to offer a voltage range.
- The next consideration is the **continuous current** the controller will need to supply.
- The **Control method** is another important consideration. Control methods include analogue voltage, I^2C, PWM, R/C, UART (a.k.a. serial).
- The final consideration is a practical one: **Single vs. dual** (double) motor controller.

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Tethered Control

- Direct Wired Control
- Wired Computer Control
- Ethernet
  - Advantages
    - Robot can be controlled trough the Internet from anywhere in the world
    - The robot is not limited to an operating time since it could use Power over Ethernet (PoE).
    - Using Internet Protocol (IP) can simplify and improve the communication scheme.
    - Same advantages as with direct wired computer control
  - Disadvantages
    - Programming involved is more complex
    - The tether can get caught or snagged (and potentially cut)
    - Distance is limited by the length of the tether
    - Dragging a long tether adds friction and can slow or even stop the robot from moving

Wireless - Infrared

- Advantages:
  - Low cost
  - Simple TV remote controls can be used as controllers

- Disadvantages:
  - Needs to be line of sight
  - Distance is limited

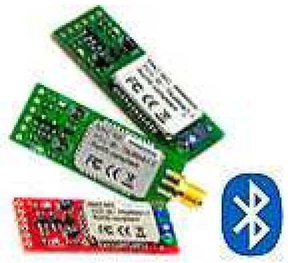
Wireless – Radio Frequency (RF)

- Advantages:
  - Considerable distances possible
  - Setup can be straightforward
  - Omni directional (impeded but not entirely blocked by walls and obstructions)

- Disadvantages:
  - Very low data rate (simple commands only)
  - Pay attention to the transmission frequencies – they can be shared

Wireless - Bluetooth

- Advantages:
  - Controllable from any Bluetooth enabled device (usually additional programming is necessary) such as a Smartphone, laptop, desktop etc.
  - Higher data rates possible
  - Omnidirectional (does not need line of sight and can travel a little through walls)
- Disadvantages:
  - Devices need to be “paired”
  - Distance is usually about 10m (without obstructions)



Wireless - WIFI

- Advantages:
  - Controllable from anywhere in the world so long as it is within range of a wireless router
  - High data rates possible

- Disadvantages:
  - Added programming required
  - Maximum range is usually determined by the choice of wireless router

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Which sensors do my robots need?

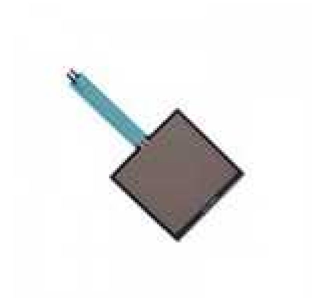
- You need to first ask yourself “what do I want or need the robot to measure?”

Sensors - Contact

- Push button / Contact switch
  - Advantages: very low cost, easy to integrate, reliable
  - Disadvantages: single distance measurement

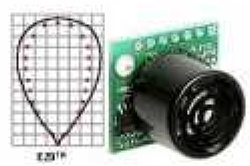


- Pressure sensor
  - Advantages: very low cost, easy to integrate, reliable
  - Disadvantages: single distance measurement



Sensors - Distance

- Ultrasonic Range Finders
  - Advantages: medium range (several meters) measurement.
  - Disadvantages: surfaces and environmental factors can affect the readings.



- Infrared
  - Advantages: low cost, fairly reliable and accurate.
  - Disadvantages: closer range than ultrasonic

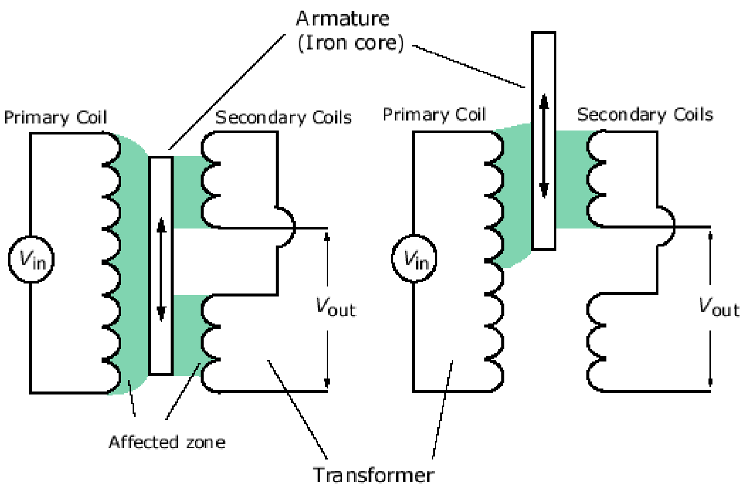
- *Laser*
  - Advantages: very accurate, very long range.
  - Disadvantages: expensive

Sensors – Distance (Continued)

- Linear Potentiometer, resistive band
  - Advantages: position is absolute. A resistive band requires pressure to be applied at a given position.
  - Disadvantages: range is very small

Sensors – Distance (Continued)

- Linear Variable Differential Transformer:
  - a transducer for measuring linear displacement.



Sensors – Distance (Continued)

- Stretch and Bend Sensors
  - Advantages: useful where an axis of rotation is internal or inaccessible.
  - Disadvantages: not very accurate, and only small angles can be measured.

- Stereo Camera System
  - Advantages: can provide depth information and a good feedback about a robot’s environment.
  - Disadvantages: complex to program and use the information

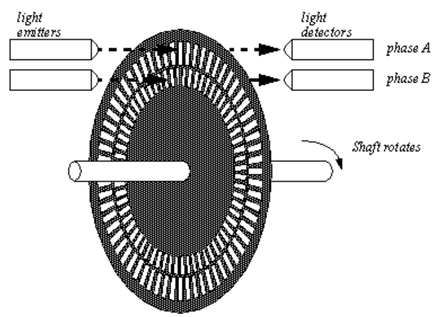
Sensors - Positioning

- Indoor Localization (room navigation)
  - Advantages: excellent for absolute positioning.
  - Disadvantages: requires complex programming and the use of markers.

- GPS
  - Advantages: does not requires markers or other references.
  - Disadvantages: can only function outdoors.

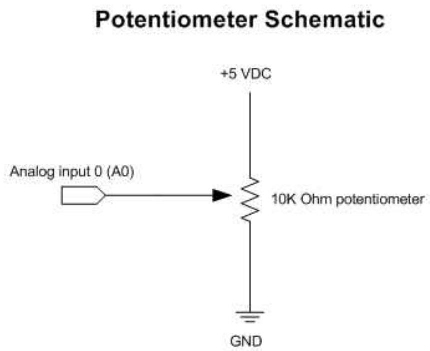
Sensors – Rotation (Continued)

- Encoders
  - Advantages: accurate.
  - Disadvantages: for optical encoders, the angle is relative (not absolute) to the starting position.



Sensors - Rotation

- Potentiometer
  - Advantages: simple to use, inexpensive, reasonably accurate, provides absolute readings.
  - Disadvantages: most are restricted to 300 degrees of rotation.



Sensors – Rotation (Continued)

- Gyroscope
  - Advantages: no moving “mechanical” components.
  - Disadvantages: the sensor is always subjected to angular acceleration whereas a microcontroller cannot always take continuous input, meaning values are lost, leading to “drift”.

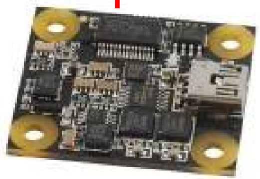
Sensors – Attitude

- Compass
  - Advantages: provides absolute navigation.
  - Disadvantages: greater accuracy increases the price.

Sensors – Attitude (Continued)

- Accelerometers
  - Advantages: they do not require any external reference or marker to function and can provide absolute orientation with respect to gravity, or relative orientation.
  - Disadvantages: they only approximate the traveled distance and cannot precisely determine it.

- IMU’s
  - Advantages: it is a very reliable way of measuring the robots attitude without using external references (besides the earth’s magnetic field).
  - Disadvantages: can be very expensive and is complex to use.



Sensors – Environmental Conditions

- Light Sensor
  - Advantages: usually very inexpensive and very useful.
  - Disadvantages: cannot discriminate the source or type of light.

- Sound Sensor
  - Advantages: inexpensive, reliable
  - Disadvantages: more meaningful information requires complex programming.

Sensors – Environmental Conditions

- Thermal Sensor
  - Advantages: they can be very accurate.
  - Disadvantages: more complex and accurate sensors can be more difficult to use.

- Thermal Camera
  - Advantages: differentiate objects from the background based on their thermal signature
  - Disadvantages: expensive.

Sensors – Environmental Conditions

- Humidity Sensor
  - Advantages: inexpensive and very useful.
  - Disadvantages: expensive if accuracy is required.

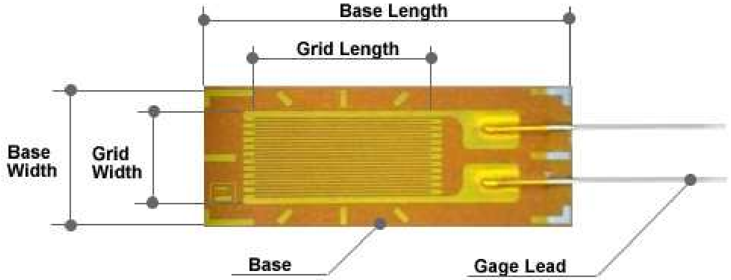
- Gas Sensor
  - Advantages: These are the only sensors which can be used to accurately detect gas.
  - Disadvantages: inexpensive sensors may give false positives or somewhat inaccurate readings and should therefore not be used for critical applications.

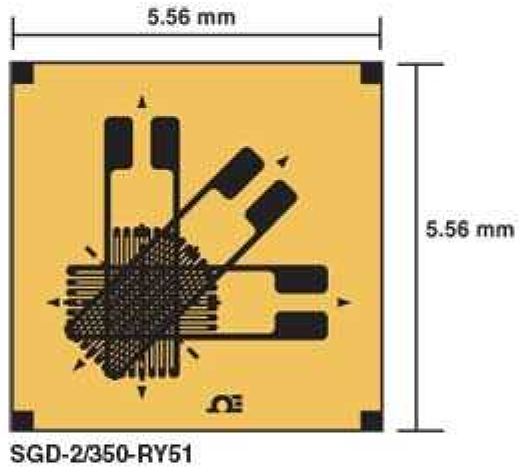
Sensors – Environmental Conditions

- Magnetometers
  - Advantages: can detect ferromagnetic metals.
  - Disadvantages: some times the sensors can be damaged by strong magnets.

Sensors - Strain Measurement

- Strain Gage: consists of a thin foil of metal, usually constantan, deposited as a grid pattern onto a thin plastic backing material, usually polyimide.



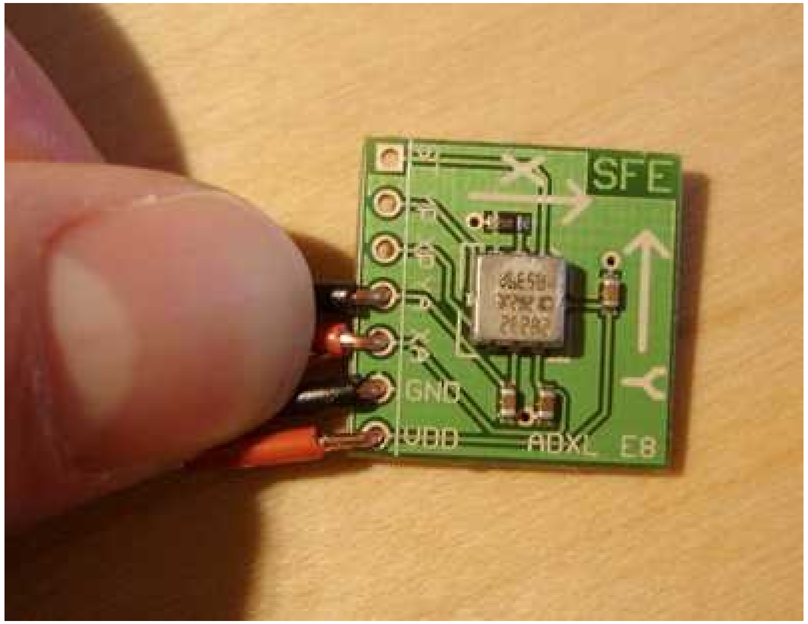


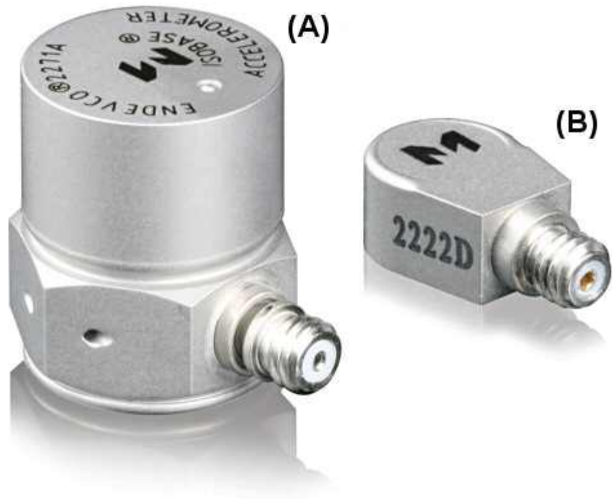
Sensors - Force Measurement

- Load Cell: a sensor used to measure a force.

Sensors - Vibration Measurement

- Accelerometers: a sensor designed to measure continuous mechanical vibration.





Sensors – Etc.

- RFID
  - Advantages: RFID tags are usually very low cost and can be individually identified.
  - Disadvantages: not useful for measuring distance, only if a tag is within range.

How to make a robot

- Choosing a Robotic Platform.
- Making Sense of Actuators.
- Understanding Microcontrollers
- Choosing a Motor Controller
- Controlling your Robot
- Using Sensors
- Getting the Right Tools
- Assembling a Robot
- Programming a Robot

http://www.robotshop.com/blog/en/how-to-make-a-robot-lesson-1-3707

What Language to Choose?

- **Assembly**: machine code which is very tedious to use.
- **Basic**: one of the first widely used programming languages, it is still used by some microcontrollers (Basic Micro, BasicX, Parallax) for educational robots.
- **C/C++**: one of the most popular languages, C provides high-level functionality while keeping a good low-level control.
- **JAVA**: it is more modern than C and provides lots of safety features to the detriment of low-level control. Some manufacturers like Parallax make microcontrollers specifically for use with Java.
- **.NET/C#**: Microsoft's proprietary language used to develop applications in Visual Studio. Examples include Netduino, FEZ Rhino and others.
- **Python**: one of the most popular scripting languages. It is very simple to learn and can be used to put programs together very fast and efficiently.

Language Examples

- Arduino microcontrollers use Arduino software and are re-programmed in Processing.
- Basic Stamp microcontrollers use PBasic
- Basic Atom microcontrollers use Basic Micro
- Javelin Stamp from Parallax is programmed in Java
- mBed uses C through website.

Programming Tips

- Develop a file system on your computer to easily look up the necessary code.
- Document everything within the code using comments.
- Save different versions of the code – do not always overwrite the same file.
- Raise the robot off the table or floor when debugging.
- If code does something that does not seem to be working correctly after a few seconds, turn off the power.
- Subroutines may be a bit difficult to understand at first, but they greatly simplify your code.